Emerging technologies are revolutionizing the rootstock rooting process in agricultural engineering through in vitro techniques

Dzhabrail M. Bamatov[1*], *Ismail* L. Daudov[2], and *Magomed* M. Arsanov[2]

[1]Grozny State Oil Technical University named after Academician M. D. Millionshchikov, 100, Prospekt Kh. Isaeva, Grozny, 364061, Russia
[2]Chechen State University, 32, Sheripova str., Grozny, 364024, Russia

Abstract. This article endeavors to showcase the seamless integration of cutting-edge technologies into the agricultural sector, with a specific emphasis on their application within biotechnology laboratories specializing in in vitro cultivation. The pioneering technology at the heart of this project centers on the automated detection of viral symptoms in micro-cut rootstocks grown in nutrient-rich substrates. Furthermore, we will delve into a comparative analysis, contrasting laboratories equipped with automated processes against those devoid of such advancements, specifically in the context of in vitro cultivation of subject-rooted plants in identical nutrient-rich environments. The anticipated annual financial gains stemming from the incorporation of an automated system into the in vitro laboratory are projected to reach an impressive 1.8 million Russian rubles.

1 Introduction

The adoption of cutting-edge technologies, particularly the infusion of automation processes, into modern industries is an imperative response to the evolving landscape. The fundamental driving force behind the assimilation of these innovative technologies into industrial workflows revolves around three key objectives: the reduction of production timelines, the lowering of overall production costs, and the optimization of resource allocation. Additionally, a pivotal facet of embracing novel technologies lies in their capacity to curtail wastage across various processes [1].

However, within the realm of agricultural industries, particularly those operating in the intricate field of biotechnology, the seamless integration of automation processes poses a unique set of challenges. This challenge emanates from the fact that machines, despite their sophistication, may not possess the innate intelligence required to address unforeseen and unprogrammed issues that may arise during operations. Consequently, when contemplating the adoption of novel approaches within in vitro biotechnology laboratories, the decision-making process must transcend the conventional metrics of time and cost efficiency,

* Corresponding author: bamatov93@mail.ru

prioritizing instead their harmonization with the environment and alignment with the workflow [2].

The contemporary horizon unveils a promising landscape characterized by breakthrough technologies and transformative products. However, it is crucial to acknowledge and address the persistent and imminent challenges that confront humanity. Chief among these are the relentless specters of global warming, escalating overpopulation, and entrenched poverty, each of which wields distinct and profound effects on a global scale.

In response to these challenges, Ltd Scientific Production Firm "Sady Chechni" has embarked on a dedicated mission to research and develop healthy planting materials for berry and fruit crops. This article delves deep into the realm of agriculture, emphasizing the pressing need for adaptive transformations in the pursuit of cultivating resilient and high-yielding trees ideally suited for the unique climatic conditions of the Chechen Republic and analogous regions.

Within the realm of the agro-industrial complex, the sorting of agricultural products stands as one of the least automated technological processes. In the traditional landscape of agricultural production, this sorting practice begins with the harvesting phase and persists, intermittently, throughout storage and the preparatory stages before sale and packaging. Typically, this sorting procedure relies heavily on manual labor, entailing a visual inspection of each individual unit of produce followed by its placement into the appropriate container.

On occasion, there are efforts to introduce partial automation into the sorting process, often utilizing a moving conveyor belt. In this mechanized setup, agricultural products are gently conveyed along the belt, while operators stationed on both sides conduct inspections and manually adjust the product's path based on specific attributes. This sorting process is versatile, applicable to various agricultural products such as root tubers, apples, pears, tomatoes, and more.

The horticultural sector is also in dire need of embracing automation in production and the assimilation of digital technologies. In the current phase of its evolution, the production of robust planting material is undergoing rapid advancement and is intricately linked with the utilization of cutting-edge biotechnological methods [3]. One standout approach is micropropagation, demonstrating multiplication factors that are hundreds, if not thousands, of times more efficient compared to any traditional techniques [4]. The method involving apical meristems, followed by the microclonal propagation of genetically sound clones, has gained substantial global traction.

2 Materials and method

This innovative method empowers the rapid and abundant production of healthy, genetically uniform planting material. Micropropagation technology is a global phenomenon, finely tuned to cater to the unique varieties and rootstocks prevalent in various countries. However, in Russia, where distinctive plant varieties and rootstocks flourish under specific weather conditions, the absence of optimized nutrient media poses a significant challenge.

Although breeding rates on standard nutrient media surpass those of traditional methods, they still fall short of the potential realized with optimized media. This limitation ultimately impacts nursery efficiency. The microclonal propagation technology for fruit and berry crops has reached a high degree of refinement, facilitating the production of a substantial volume of uniform planting material [5].

To further elevate this process, the optimization of the nutrient medium and the introduction of automation into the microclonal reproduction process can substantially amplify the in vitro multiplication factor. Consequently, this would greatly enhance the efficiency of acquiring healthy planting material.

3 Problems and innovative solutions in agriculture

Diverse methodologies are readily available in the market and can be applied across industries to optimize workflows, ultimately leading to increased production rates while concurrently minimizing the generation of undesirable waste. In the scope of this research endeavor, we introduced an innovative approach by integrating an accumulation rack alongside a robotic stacking system within our in vitro laboratory [6].

Prior to their integration into the automated storage system (ASS), a variety of plant samples, housed in flasks, were methodically placed onto plastic trays with dimensions of 600x400 mm. These trays featured strategically designed shallow cells, perfectly tailored to the diameters of the test tubes, ensuring their stability during handling and transportation. Each pallet was thoughtfully designed to accommodate 24 test tubes, and the tray-loading process was executed meticulously at an operator's workstation located in a neighboring room, adjacent to the storage facility.

Following this meticulous preparation, the trays, each laden with test tubes, embarked on their journey through a precision-engineered feed conveyor system. Guided by this conveyor, they were transported seamlessly by a sophisticated stacker robot to their designated location within the racking array, where they could be efficiently and systematically stored.

In accordance with the provided protocol, the robotic stacker, as depicted in Figure 1, follows a precise sequence of actions. Notably, it bypasses all storage cells and skillfully maneuvers the manipulator deep into each cell. This strategic approach ensures that the embedded cameras capture comprehensive data about the test tubes they encounter during their traversal. When the cameras detect any anomalies, such as defects in the nutrient medium or the plants themselves, the automation system logs both the cell's identification number and the precise location of the flawed test tube on the pallet. This critical information is methodically stored within the information system (IS), awaiting the moment when all pallets are slated for collective removal from the system [7].

Upon the culmination of the growth period, the information system sends a signal to the automation system, prompting the systematic extraction of all pallets from the storage system. These pallets are then systematically conveyed by the stacker robot to an adjacent room, where they await further processing at the operator's workstation. The operator initiates the assessment process by scanning the pallet's barcode for identification purposes. Notably, this procedure can also incorporate the use of RFID technology for enhanced precision. This scanning action prompts the information system to present pertinent data regarding the presence and specific location of defective tubes on the workstation monitor screen. Alternatively, this information may be conveyed through an alternative means, such as beam illumination.

Armed with this insightful information, the operator meticulously segregates the defective tubes from those deemed to be in sound condition. It's imperative that the storage system be well-illuminated across all shelf areas. Alternatively, the robot's control algorithm should be designed to intelligently consider the periodic rotation of tubes through well-lit areas, ensuring comprehensive inspection coverage [8].

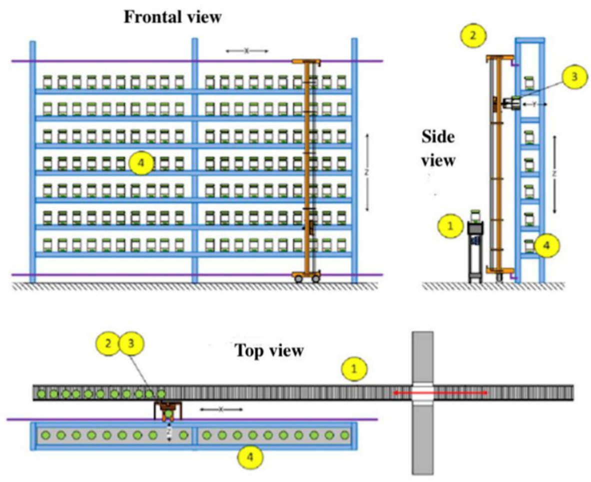

Fig. 1. The system Sketch "Accumulation rack with stacker robot".

The stacker robot's workflow is as follows: Initially, test tubes containing samples are introduced into the system via a reversible conveyor (1). A stacking robot (2), equipped with both a camera and a gripper-manipulator for handling the test tubes (3), takes charge of transferring these tubes to a storage rack (4), ensuring an even distribution across all its shelves.

These racks can be arranged in dual rows and effectively managed by a solitary stacker robot. At predefined intervals, the robotic stacker (2) guides the camera, an integral component of the tracking and control system (CS), along a specific trajectory crafted to meticulously assess the condition of the contents within all test tubes containing samples. The CS conducts a thorough analysis of the medium within the test tubes, promptly alerting the stacker robot (2) in case of any deviations from the specified standards, leading to the removal of the problematic test tube from the system.

As the growth period concludes, the CS issues a signal instructing the stacker robot (2) to initiate the collective removal of all tubes from the system via the conveyor (1).

To ensure optimal operation, the storage system is uniformly illuminated throughout all shelf areas. Alternatively, the robot's control algorithm is intelligently designed to consider the systematic rotation of tubes through well-illuminated sections, thereby guaranteeing comprehensive inspection coverage.

The table below (Table 1) presents a comparative analysis between two laboratories: one equipped with an automation system process and the other without, regarding the percentage of successfully rooted plants in vitro.

Table 1. The comparative test (rooted plants) results between two laboratories with and without automated system.

Genotype	The number of rooted plants (1000 piece) with automation system	The number of rooted plants (1000 piece) without automation system
VSL-2	784	651
VSL-1	683	540
VSV-1	844	689
B-9	861	759
Kuban-86	683	649
L-2	750	761
Overall in %	77	67

The data from the aforementioned table (Table 1) unmistakably highlights that the integration of an automation system results in a notable 10% upsurge in rooted plant production. For a company annually producing three hundred thousand rootstocks, this equates to a substantial addition of 30,000 plants. In financial terms, this surge in production translates into a yearly profit of 1.8 million Russian rubles, computed based on a per-rootstock price of 60 Russian rubles.

Additionally, it becomes evident that the technology of micropropagation for fruit and berry crops has reached a well-developed stage, enabling the generation of significant quantities of standardized planting material. The fine-tuning of nutrient mediums and the implementation of automation in the microclonal reproduction process play pivotal roles in significantly elevating the in vitro multiplication factor. Consequently, this drives a considerable improvement in the overall efficiency of procuring healthy planting material.

4 Conclusion

The development of an automated system harnessing augmented reality (AR) technologies for the assessment of culture medium contamination in explant cultivation promises a substantial leap forward. This innovation holds the potential to inject greater flexibility into select research stages, consequently expediting the initial sorting of healthy and unhealthy plants. Throughout our research, we rigorously scrutinized the integration of automation components within the microclonal reproduction process. The implementation of an automated system within the in vitro laboratory yields several noteworthy benefits.

Elevating the survival rate of seedlings can be attributed to several key factors:

- Substantial reduction in the time required for human presence within the biotechnology laboratory and their interaction with matured seedlings. This decrease in human intervention significantly lowers the risk of seedlings being exposed to various viruses and pathogens.
- Enhanced efficiency in the examination of explants for viruses and diseases, expediting the sorting process by swiftly distinguishing between healthy and unhealthy plants during the initial stages of growth.
- Rapid acquisition of real-time information concerning the condition of matured seedlings, enabling more informed decision-making in managing the seedling growth process.

Collectively, these factors contribute significantly to an appreciable increase in the survival rate of seedlings.

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